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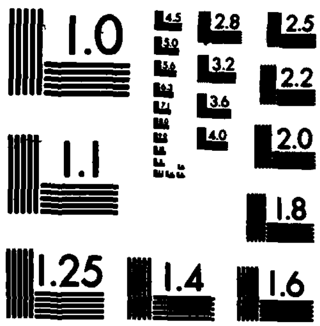
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MEMORANDUM No. 3647

ROYAL SIGNALS & RADAR ESTABLISHMENT

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MULTIPLE PASSBAND TRANSDUCERS FOR TONE SELECTION FROM A FREQUENCY COMB GENERATOR

Author: C L West

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TITLE: MULTIPLE PASSBAND TRANSDUCERS FOR TONE SELECTION FROM A FREQUENCY COMB GENERATOR

AUTHOR: C L West

DATE: May 1984

SUMMARY

This memorandum describes the design procedures used to realise switchable multiple passband surface acoustic wave transducers. These transducers may be used in series to act as selectors of tones from a comb generator. Experimental results of devices which can select between sixteen tones separated by 1 MHz at a centre frequency of 100 MHz are given.

UNLIMITED

1 INTRODUCTION

The small physical size of a surface acoustic wave (SAW) transversal finite impulse response bandpass filter, flexibility of available frequency response and relative low cost in production has lead to many potential applications for these devices (1). The basic SAW delay line consists of a substrate material (usually a piezoelectric) with an optically polished surface and two transducers for conversion between electrical and acoustical signals. In many devices the role of these transducers is not only to convert from electrical to acoustical energy but also to filter it. The impulse response of a single transducer is directly related to its geometry; the relative finger positions determine the phase and the source strength associated with the fingers determines the amplitude of the response. The frequency response of such a transducer may be easily calculated by applying Fouriers theorem to this impulse response. SAW devices are usually used to select a single band of frequencies from a wide band input signal. It is possible, however, to design SAW devices which have several passbands in their response; a feature which may have significant advantages in certain applications. Consider the use of a SAW transversal filter to select a single frequency from a set of 2^n equally spaced tones. The individual tones in this spectrum would ideally be equal in magnitude and would be separated by a constant frequency offset from their neighbours. An obvious solution to tone selection would involve the use of 2^n individual filters; each filter would be designed to select a single tone while rejecting all others and would have to be fed individually from the comb generator. This approach would introduce severe power splitting losses for large values of n and become untenable. An alternative, less conventional, approach would involve the use of SAW filters with multiple passband responses.(2,3) The physical construction of such devices will be discussed later but their operation relies on the selection between pairs of filters with interleaved passband responses. This selection reduces the number of tones present by a

factor of two and subsequent filtering can result finally in the isolation of a single tone. In this approach 2n filters would be required for our scenario. The number of filters can be further reduced to n/2 by enabling the individual transducers to switch between the interleaved passband responses and by using two different transducer designs in a filter. For n = 4, ie 16 tones, the number of filters required would be reduced from 16 to 2;a very significant saving. Figure 1 demonstrates how this technique would operate for four tones (n = 2), where the tone separation is Δf. Transducer A has passbands of width Δf interleaved with stopbands of width Δf. States 1 and 2 of this transducer are complementary. Transducer B has passbands and stopbands of width $2\Delta f$ which correspond directly with pairs of switched states in transducer A. Selection of particular states of these two transducers will result in allowing only one of the bands of width Δf to pass unattenuated (fig 1e). This passband may then be used to select from a comb of frequencies (fig 1f) resulting in the isolation of a single tone (fig 1g). Other tones are selected using different combinations of the states of the two transducers. The realisation of these selectable multiple passband transducers will be the subject of the rest of this memorandum.

2 THE DESIGN OF SWITCHABLE SAW MULTIPLE PASSBAND TRANSDUCERS FOR TONE SELECTION

The procedure for calculating the impulse response of a restricted overall bandwidth multiple passband frequency response is shown schematically in figure 2. The required frequency response for the device is equivalent to the convolution of a picket fence function (fig 2a) with a single passband function (fig 2b), followed by multiplication with a band restricting envelope function (fig 2d). The Fourier transforms of each of these basis functions can be easily calculated and the final impulse response of the device may be calculated by the

application of the convolution theorem to these functions (4). In the present application, however, the square passbands depicted in figure 2 are excessively severe and would result in excess complication in the SAW filter pattern. For tone selection it is only necessary to suppress efficiently at frequencies corresponding to the unwanted tones of the comb while maintaining minimum loss conditions at frequencies corresponding to the wanted tones. A function which can demonstrate such properties is the raised odd cosine series.

$$g(f) = A_o + \sum_{m=1}^{m=n} A_m \cos((2m - 1)2\pi f/\Delta f) \qquad (1)$$

where Δf is the repeat period of the function.

The function $(g(f) - A_o)$ yields symmetrically shaped bandpass functions which are contiguous and in which neighbouring passbands "alternate in phase" (see fig 3). The coefficients of the series are chosen to produce "sets" of maxima which have equal amplitude and which coincide with the frequencies of the tone generator. The function g(f) is completed with a coefficient A_o which has the same amplitude as the maxima in the function $(g(f) - A_o)$. The phase of this leading term is chosen to suppress the response of alternate sets of maxima while enhancing the remaining maxima. Changing the phase of A_o by π will result in the passbands and stopbands being interchanged. This property is demonstrated for a real device in figure 3. The order to which the function g(f) is expanded is determined by the number of tones that are contained within a single passband.

For tone selection purposes the n turning points within the primary passband of the function (centred at f = 0) are at frequencies defined by the equations

$$\begin{aligned} f &= \pm (2k - 1)\, \Delta f/4n \qquad \text{for n even} \qquad k = 1 \ldots n/2 \\ f &= \pm k\, \Delta f/2n \qquad \text{for n odd} \qquad k = 0 \ldots (n - 1)/2 \end{aligned} \qquad (2)$$

The function g(f) must have equal values at each of these turning points and $(\frac{n}{2} - 1)$ equations for n even, $((\frac{n-1}{2})$ equations for n odd), can be formulated using equations (1) and (2). A further $(\frac{n}{2})$ equations for n even, $((\frac{n-1}{2})$ equations for n odd), can be formulated by differentiating equation (1) and specifying the frequencies defined by equation (2) as turning points. Thus in both n even and n odd cases we can identify (n - 1) equations which can be solved simultaneously to determine the relative values of the coefficients A_m (see Appendix 1). The results of this calculation for n = 1 to 8 are given in table 1 and figure 4. In the table the coefficient A_1 has been arbitrarily set to unity. Note that changing the sign of A_o will exchange the positions of the passbands and the stopbands. This change of sign is the basis for the switchable multiple passband transducer.

So far in this section we have calculated the functional form of a suitable frequency response for tone selection and demonstrated its potential to achieve switchability. As was explained in the introduction it is more convenient to operate in the time domain while designing SAW filters and so the frequency domain function must be Fourier transformed to give the required impulse response. This transformation is made particularly easy by the functional form of g(f). Cosine functions in the frequency domain correspond to an even valued pair of delta functions in the time domain (4), while the A_o term, which corresponds to a continuum over all frequencies, is a simple delta function at the origin in the time domain (4).

The implementation of such a set of delta functions in a real device is limited by practical considerations. Each delta function must be replaced by a physically realisable rectangular impulse of finite time duration (fig 5b) with the result that the frequency domain response will be bandlimited by an envelope function which is centred at $f = 0$. To centre this envelope function at a useful frequency, f_c, it is necessary to convolve the frequency response

with the even frequency pair, $\pm f_c$. The final impulse response is thereby modulated with a cosine function in time and it is this form of the impulse response that can be directly implemented as a pattern in a SAW device (fig 5, bottom). The duration of the individual bursts will determine the overall bandwidth of the device and the relative timing and amplitudes of the bursts will correspond to the original impulse responses of table 1. In a SAW device these timings are translated to a physical pattern on a piezoelectric substrate using the relation $d = v\tau$, where v is the SAW velocity and τ is the relative timing of the components from a chosen origin. Practical devices will, of course, have to consider the different velocities with which SAW propagating on a free and a metallized surface to ensure accurate positioning of stopband and passband frequencies.

3 EXPERIMENTAL RESULTS

SAW devices have designed using the methods described in the previous section which will select a single tone from a set of sixteen tones separated by 1 MHz near a centre frequency of 100 MHz. The theoretical frequency responses for the four transducers, and their expected combined responses, are shown in figure 6. In particular fig 6b shows the combined responses which will select for a single frequency tone from a set of 16. The transducers were designed to have one, two, four and eight tones in adjacent passbands (table 1 and figure 4) and each device consists of two of these transducers with a full transfer multistrip coupler (fig 7). In figure 7 the bonding arrangement is just visible; the central transducer element is connected with separate bondwires and can be connected in phase or out-of-phase with the remaining part of the array to realise the switchable multiple passbands. The measured insertion loss characteristics for a set of these filters is given in figure 8. There is good agreement between predicted and theoretical responses (compare fig 6a with

fig 8 directly). At present the switching is achieved by hardwire connections but it would be possible to switch these states electrically.

The devices have been used to demonstrate tone selection from a continuous comb of frequencies in which each tone is separated from its neighbour by 1 MHz. These results are given in figure 9 and figure 10. In figure 9 we show the selection of every fourth tone using the simpler of the two filters depicted in figure 7. The unwanted tones are typically suppressed by > 30 dB. Figure 10 demonstrates the use of the two filters of figure 7 operating together for the isolation of a single tone from a set of 16 tones. The suppression in this latter case is > 25 dB. This degradation in performance is due to the non ideal behaviour of the second filter in two respects; firstly, the design of the second device did not produce the optimum suppression of unwanted tones; secondly, the nulls of this filter did not coincide identically in frequency spacing with those of the first filter. Future designs could, of course, improve on the fidelity of the nulls and is not seen as a fundamental problem to the operation of these type of devices.

The component transducers of the multiple passband transducers have an intrinsic third harmonic response. Unfortunately the devices have been designed with a multistrip coupler which operates well at the fundamental but not at the third harmonic. Experimental results have been obtained, however, for the third harmonic response of the switchable multiple passband transducer with a test transducer (figure 11). The responses, for untuned transducers, show the multiple passband structure, and have been shown to demonstrate similar switching properties as the transducers operated at the fundamental. It is possible using these responses to extend the operating range of such devices.

4 CONCLUSION

In this memorandum I have described the procedure used to design a switchable multiple passband transducer for use as a tone selector with a comb generator,

Two devices have been made which, when used in series, can select a single tone from a set of sixteen tones with only 25 dB insertion loss. The fidelity of the response is dependent on careful design but is based on simple considerations. The final devices benefit from the common SAW feature of one stage photolithography which means that the devices should be reproducible in large numbers. The size of the device will depend on the actual centre frequency, f_c, but will be approximately $(2000/f_c\ \Delta F)$ mm where f_c and ΔF are measure in MHz.

ACKNOWLEDGEMENT

The author would like to thank Dr M F Lewis for many useful discussions.

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APPENDIX 1

MULTIPLE PASSBAND RESPONSES BASED ON AN ODD HARMONIC FOURIER COSINE SERIES.

THE DETERMINATION OF THE COEFFICIENT FOR THE SPECIFIC CASE OF TONE SELECTION

The equation

$$g(f) = A_o + \sum_{m=1}^{m=n} A_m \cos((2m - 1)2\pi f/\Delta f) \qquad (A1)$$

is to be solved for equal valued maxima which occur at frequencies

$$\begin{aligned} f &= \pm (2k - 1)\, \Delta f/4n \quad \text{for } n \text{ even} \quad k = 1 \ldots n/2 \\ f &= \pm k\, \Delta f/2n \quad \text{for } n \text{ odd} \quad k = 0 \ldots (n - 1)/2 \end{aligned} \qquad (A2)$$

Two conditions can be applied

1) The maxima have equal amplitude

2) The maxima are turning points of the function (by differentiation)

These conditions result in the following sets of equations which must be solved simultaneously.

I) <u>for n even</u>

$$\sum_{m=1}^{m=n} A_m\{\cos(\pi(2m-1)(2k-1)/2n) - \cos(\pi(2m-1)/2n)\} = 0 \qquad k = 2 \ldots n/2$$

$$\sum_{m=1}^{m=n} A_m(2m-1) \sin(\pi(2m-1)(2k-1)/2n) = 0 \qquad k = 1 \ldots n/2$$

$$A_1 = 1$$

$$A_o = \sum_{m=1}^{m=n} A_m \cos(\pi(2m-1)/2n)$$

II) <u>for n odd</u>

$$\sum_{m=1}^{m=n} A_m\{\cos(\pi(2m-1)k/n) - 1\} = 0 \qquad k = 1 \ldots \frac{n-1}{2}$$

$$\sum_{m=1}^{m=n} A_m(2m-1) \sin(\pi(2m-1)k/n) = 0 \qquad k = 1 \ldots \frac{n-1}{2}$$

$$A_1 = 1$$

$$A_o = \sum_{m=1}^{m=n} A_m$$

A program which solves these equations on the Hewlett Packard 85F calculator (plotter and matrix ROM added), tables the resultant values of A_m (see table 1) and plots the appropriate frequency response (figure 4) is given below.

```
 10 OPTION BASE 1
 20 DIM A(7,7),B(7),X(7)
 30 RAD
 40 ON KEY# 1,"FULLPL" GOSUB 200
    0
 50 ON KEY# 2,"FULLLI" GOSUB 300
    0
 60 KEY LABEL
 70 GOTO 60
1000 MAT A=ZER@ MAT B=ZER@ MAT X
    =ZER
1005 IF N=1 THEN X9=0
1010 IF N=1 THEN 1270
1020 REDIM A(N-1,N-1),B(N-1),X(N
    -1)
1030 IF FP(N/2)>.1 THEN 1170
1040 FOR K=1 TO N/2
1050 FOR M=2 TO N
1060 A(K,M-1)=(2*M-1)*SIN((2*M-1
    )*(2*K-1)*PI/(2*N))
1070 NEXT M
1080 B(K)=-SIN((2*K-1)*PI/(2*N))
1090 NEXT K
1100 FOR K=2 TO N/2
1110 FOR M=2 TO N
1120 A(K-1+N/2,M-1)=COS((2*M-1)*
    (2*K-1)*PI/(2*N))-COS((2*M-
    1)*PI/(2*N))
1130 NEXT M
1140 B(K-1+N/2)=-COS((2*K-1)*PI/
    (2*N))+COS(PI/(2*N))
1150 NEXT K
1160 X9=PI/(2*N) @ GOTO 1260
```

```
1170 FOR K=1 TO (N-1)/2
1180 FOR M=2 TO N
1190 A(K,M-1)=(2*M-1)*SIN((2*M-1
     )*K*PI/N)
1200 A(K+(N-1)/2,M-1)=COS((2*M-1
     )*K*PI/N)-1
1210 NEXT M
1220 B(K)=-SIN(K*PI/N)
1230 B(K+(N-1)/2)=-COS(K*PI/N)+1
1240 NEXT K
1250 X9=PI/N
1260 MAT X=SYS(A,B)
1270 A1=1
1280 GOSUB 1500
1290 A0=F1
1300 RETURN
1500 F1=A1*COS(X9)
1505 IF N=1 THEN 1540
1510 FOR M=2 TO N
1520 F1=F1+X(M-1)*COS((2*M-1)*X9
     )
1530 NEXT M
1540 RETURN
1600 GOSUB 1500
1610 F0=(A0+F1)/(2*A0)
1620 RETURN

2000 PLOTTER IS 705
2010 FOR I=0 TO 3
2020 FOR J=0 TO 1
2030 LOCATE 25*I*RATIO,(25*I+20)
     *RATIO,50*J,50*J+45
2040 FRAME
2050 SCALE 0,40,-(PI*2),PI*2
2060 AXES 10,PI,40,0
2065 SCALE 0,-40,-(PI*2),PI*2
2066 N=2*I+J+1
2067 GOSUB 1000
2070 FOR X9=-(2*PI) TO 2*PI STEP
     PI/50
2080 GOSUB 1600
2085 IF F0=0 THEN 2087
2086 GOTO 2090
2087 X=-80
2088 GOTO 2100
2090 X=10*LGT(F0*F0)
2100 IF X9=-(2*PI) THEN MOVE X,X
     9
2110 DRAW X,X9
2120 NEXT X9
2125 PENUP
2130 NEXT J
2140 NEXT I
2150 LOCATE 0,100*RATIO,0,100
2160 SCALE 0,100,0,100
2170 LDIR PI/2
2180 FOR I=1 TO 4
2190 FOR J=1 TO 2
2200 LORG 9
2210 N=2*(I-1)+J
2220 MOVE I*25-4,(J-1)*50+45
2230 LABEL "N=";N
2240 NEXT J
2250 NEXT I
2260 RETURN

3000 PLOTTER IS 705
3010 SCALE 0,280,0,180
3020 LORG 5
3025 GOSUB 3600
3030 CSIZE 2.5,.6,0
3040 MOVE 35,150
3050 LABEL "COEFFICIENT"
3060 LABEL ""
3070 LABEL "A0"
3080 LABEL "A1"
3090 LABEL "A2"
3100 LABEL "A3"
3110 LABEL "A4"
3120 LABEL "A5"
3130 LABEL "A6"
3140 LABEL "A7"
3150 LABEL "A8"
3160 MOVE 70,150
3170 LABEL "COS(nx)"
3180 LABEL ""
3190 LABEL "DC"
3200 LABEL "COS(1x)"
3210 LABEL "COS(3x)"
3220 LABEL "COS(5x)"
3221 LABEL "COS(7x)"
3222 LABEL "COS(9x)"
3223 LABEL "COS(11x)"
3224 LABEL "COS(13x)"
3225 LABEL "COS(15x)"
3230 FOR N=1 TO 8
3240 MOVE 70+N*20,150
3250 LABEL "N=";N
3260 LABEL ""
3270 GOSUB 1000
3280 LABEL USING "DD.DDDDD" ; A0
3290 LABEL USING "DD.DDDDD" ; A1
3300 FOR J=1 TO N-1
3310 LABEL USING "DD.DDDDD" ; X(
     J)
3320 NEXT J
3330 FOR J=N TO 7
3340 LABEL "-"
3350 NEXT J
3360 NEXT N
3370 MOVE 250,152
3380 LABEL "SQUARE"
3390 LABEL "PASSBAND"
3400 MOVE 250,150
3410 LABEL ""
3420 LABEL ""
3430 LABEL USING "DD.DDDDD" ; PI
     /4
3440 FOR J=1 TO 8
3450 LABEL USING "DD.DDDDD" ; (-
     1)^(J+1)/(2*J-1)
3460 NEXT J
3470 RETURN
3600 MOVE 10,155
3610 DRAW 260,155
3620 MOVE 10,145
3630 DRAW 260,145
3640 MOVE 10,100
3650 DRAW 260,100
3660 MOVE 10,155
3670 DRAW 10,100
3680 FOR I=1 TO 11
3690 MOVE 40+20*I,100
3700 DRAW 40+20*I,155
3710 NEXT I
3720 PENUP
3730 RETURN
```

COEFFICIENT	COS (nx)	N= 1	N= 2	N= 3	N= 4	N= 5	N= 6	N= 7	N= 8	SQUARE PASSBAND
A0	DC	1.00000	.94281	.90000	.87470	.85838	.84704	.83873	.83239	.78540
A1	COS (1x)	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
A2	COS (3x)	-	-.33333	-.30000	-.29587	-.29708	-.29948	-.30199	-.30433	-.33333
A3	COS (5x)	-	-	.20000	.17752	.17168	.17051	.17099	.17206	.20000
A4	COS (7x)	-	-	-	-.14286	-.12732	-.12180	-.11982	-.11935	-.14286
A5	COS (9x)	-	-	-	-	.11111	.09983	.09499	.09283	.11111
A6	COS (11x)	-	-	-	-	-	-.09091	-.08236	-.07921	-.09091
A7	COS (13x)	-	-	-	-	-	-	.07692	.07029	.07692
A8	COS (15x)	-	-	-	-	-	-	-	-.06667	-.06667

TABLE 1

Coefficients of the function g(f), equation 1, which correspond to the idealized responses required for tone selection as described in the text and shown in figure 4. The A1 coefficient has been normalized to unity for comparison between the coefficients for the different filter responses and also with the ideal square passband values. N denotes the number of maxima in a given passband and nulls in a given stopband.

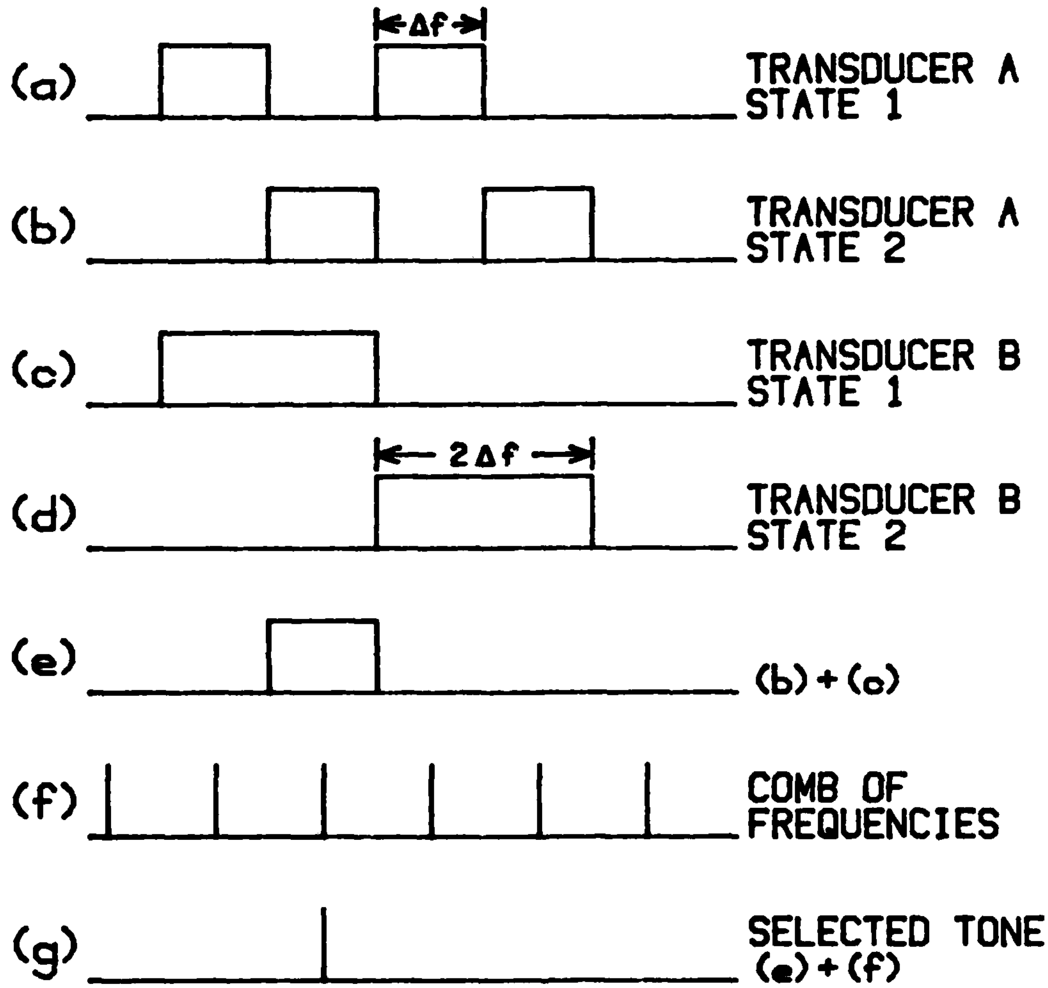


Figure 1: Demonstration of the principle involved in switchable multiple passband transducers. Transducer A has two complementary states (a and b) which can be set to either select or reject a frequency band of width Δf. Transducer B also has two complementary states (c and d) but the passbands are chosen to have width 2Δf and are positioned to correspond to a pair of switched states of transducer A. A selection of state 1 or 2 of transducer A and state 1 or 2 of transducer B will result in the isolation of a single passband (e) of width Δf within the overall bandwidth of the transducers (4Δf). This passband can then be used to select a single tone from a set of tones from a comb generator (f and g).

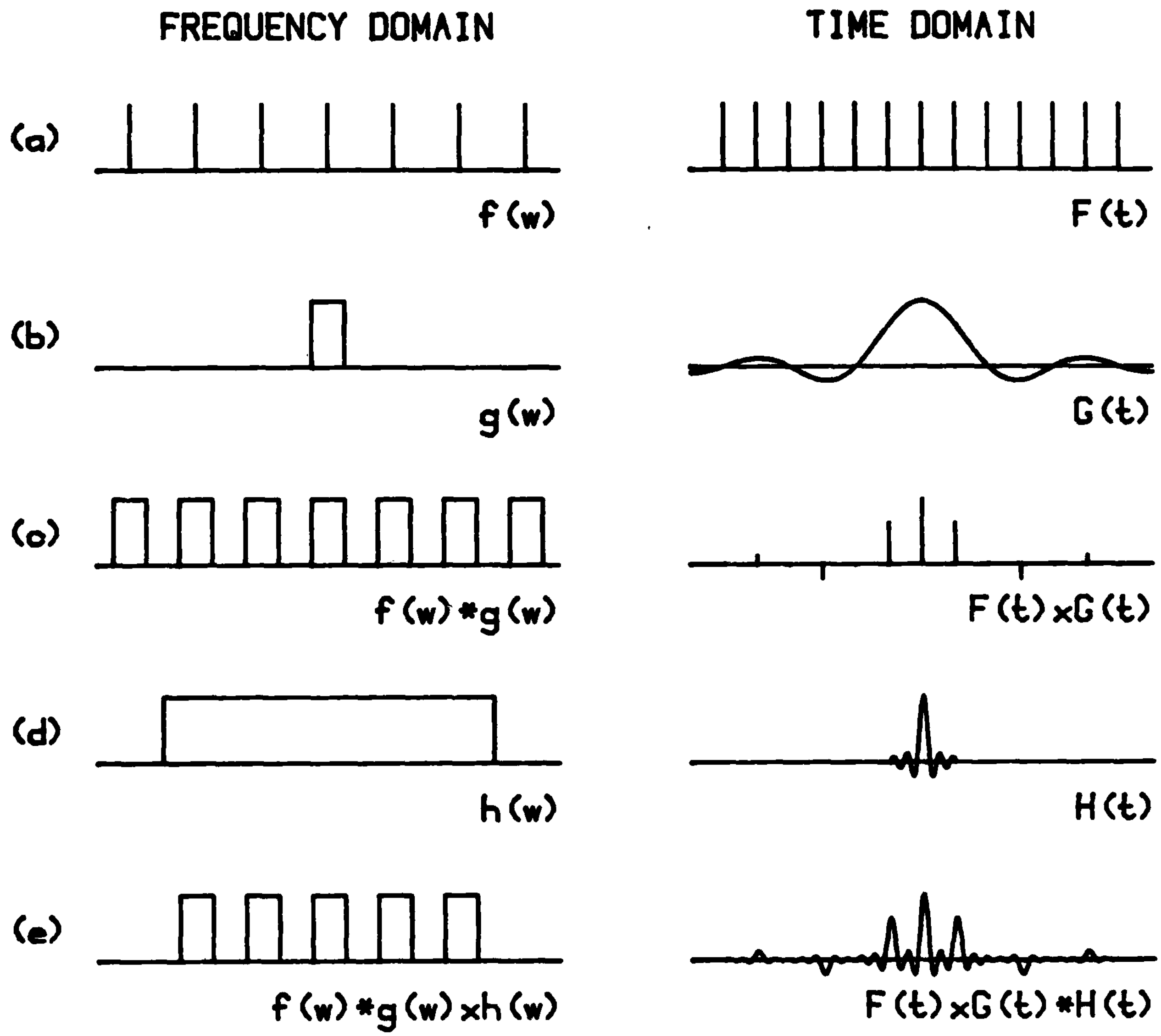


Figure 2: Step by step procedure for calculating the impulse response for multiple passband transducers. The final frequency response (e) can be considered to be the convolution of a picket fence function (a) with a single passband (b) resulting in an unlimited multiple passband response (c). This function is then multiplied by a bandlimiting envelope function (d). The three basis functions have well identified Fourier transforms and application of the convolution theorem will result in the functional form of the time domain response (ref 4).

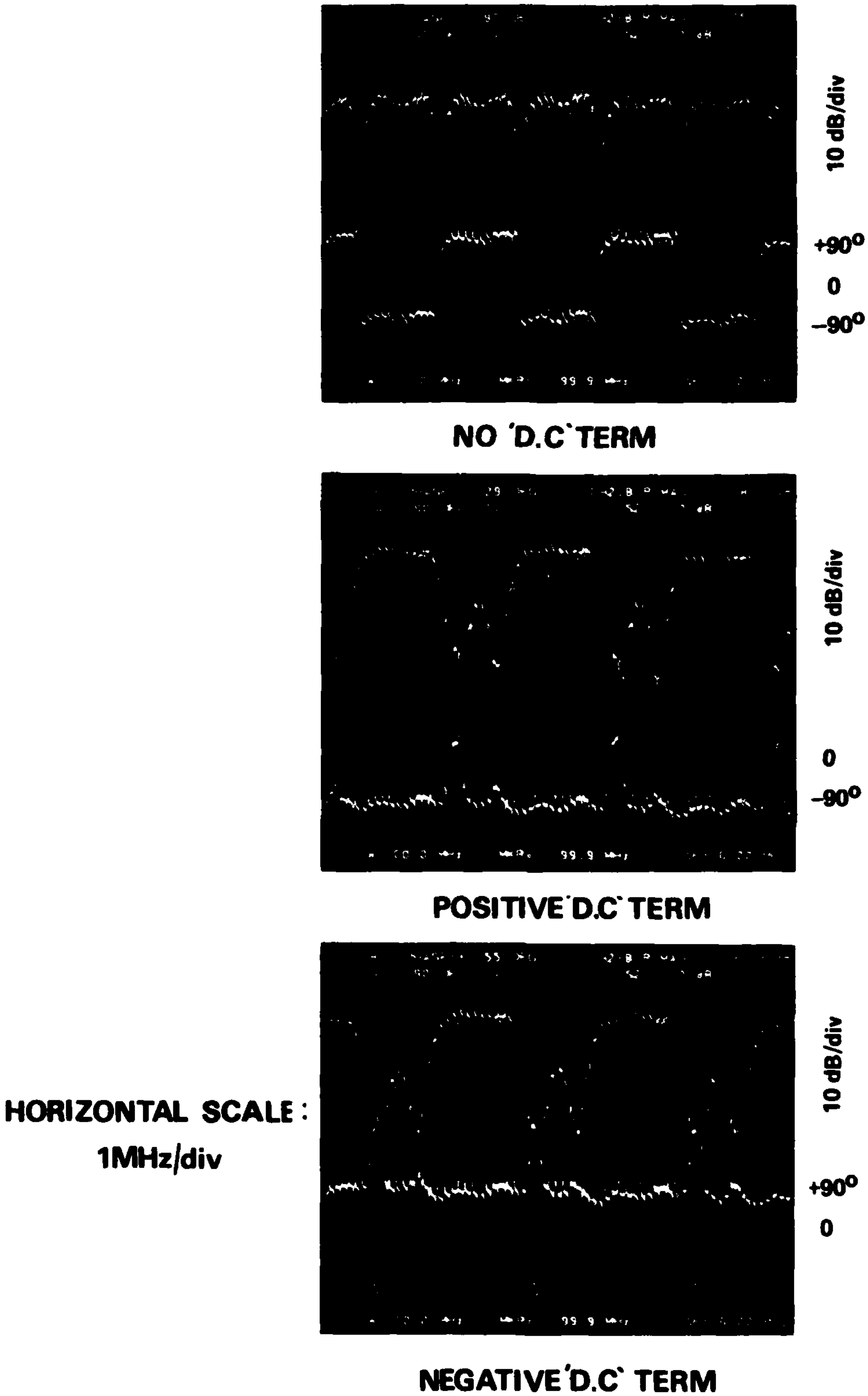


Figure 3: Demonstration of the effect of the leading 'd.c' term in the function g(f) (equation (1)) on a practical device. These results were on a test device and show the response of a transducer which has been designed to allow two adjacent tones to pass while rejecting alternate pairs of tones (figure 4: N = 2). The measurements were made using test transducers and the ripple on the traces is purely due to a lack of absorber on the device outside the transducer arrays. The top trace shows the response when the d.c term is left out of circuit. The amplitude response demonstrates sets of maxima which have equal amplitude but which have phases which alternate and are grouped in pairs. When the d.c term is included we can see that it can be chosen to be either in phase, or out of phase, with the alternate sets of maxima and switching the phase of this d.c term alone can result in the switchable multiple passband response that is required.

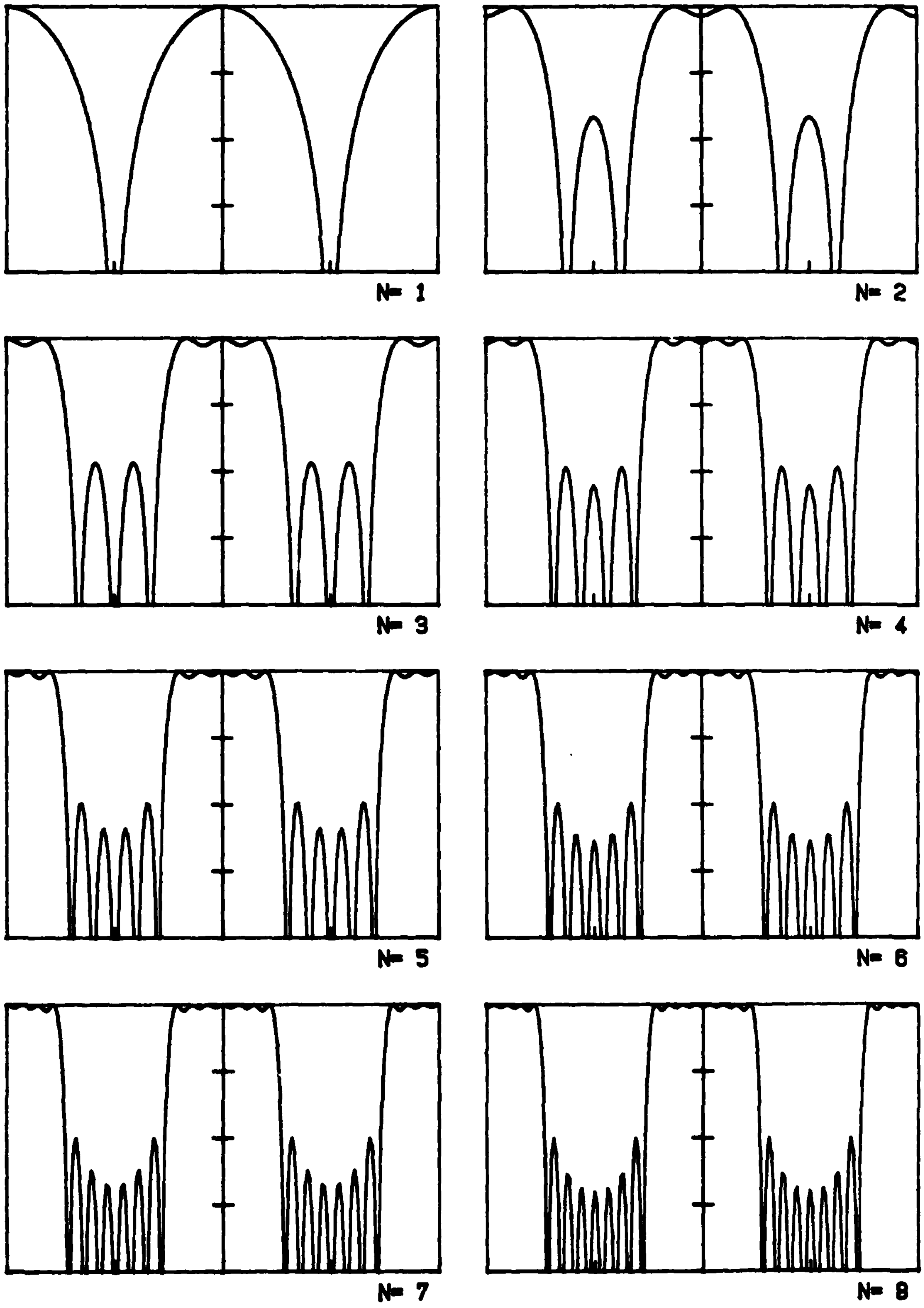


Figure 4: Calculated multiple passband responses based on the function g(f) (equation (1)). The coefficients of this series have been calculated as described in the text and are given in table 1. N denotes the number of tones in the adjacent passbands/stopbands.

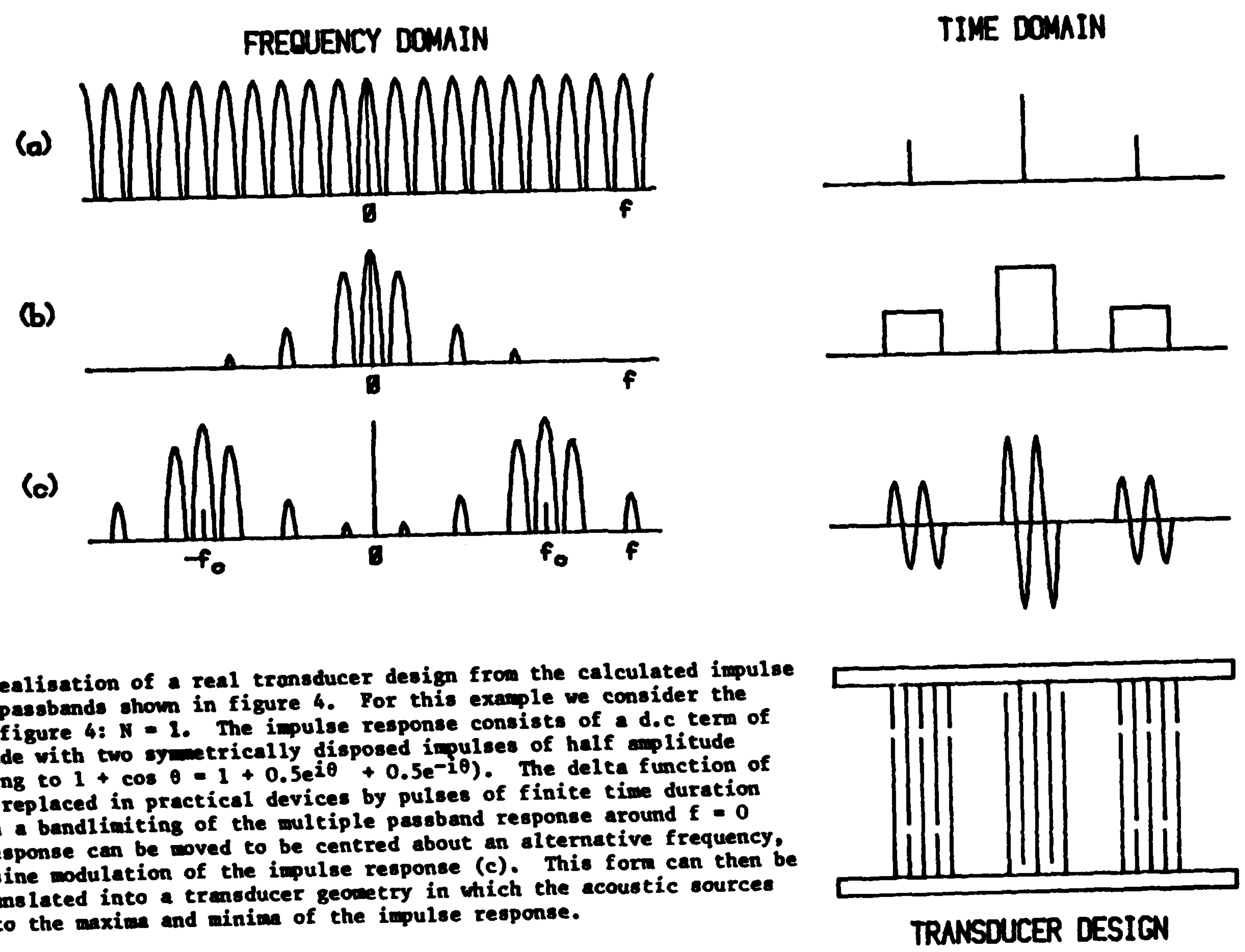


Figure 5: Realisation of a real transducer design from the calculated impulse response of passbands shown in figure 4. For this example we consider the response in figure 4: N = 1. The impulse response consists of a d.c term of unit amplitude with two symmetrically disposed impulses of half amplitude (corresponding to $1 + \cos\theta = 1 + 0.5e^{i\theta} + 0.5e^{-i\theta}$). The delta function of (a) must be replaced in practical devices by pulses of finite time duration resulting in a bandlimiting of the multiple passband response around f = 0 (b). The response can be moved to be centred about an alternative frequency, f_c, by a cosine modulation of the impulse response (c). This form can then be directly translated into a transducer geometry in which the acoustic sources correspond to the maxima and minima of the impulse response.

Figure 6(a): The calculated frequency responses of a set of multiple passband transducers designed to select one tone from sixteen, spaced at 1 MHz intervals near a centre frequency of 100 MHz. The major tic spacing of the ordinate is 10 dB, and the major tic spacing of the abscissa is 1 MHz. (a,b) Two states of transducer 1 which can select between adjacent tones. (c,d). Two states of transducer 2 which can select between adjacent pairs of tones. (e-h) The combined responses of transducer 1 and transducer 2 to isolate a single tone within a set of four tones. (i,j) Two states of transducer 3 which can select between adjacent sets of four tones. (k,l) Two states of transducer 4 which can select between adjacent sets of eight tones. (m-p) The combined responses of transducer 3 and transducer 4 which selects tones in sets of 4 from 16. The response of m and o demonstrate that in these devices we have not kept the set of four together but that they are two sets of two. This is a result of the potential application which requires that the nulls in each response will correspond identically to each other. In practical devices this results in the device passband responses being kept as central as is practicable.

Figure 6(b): The combined responses of transducers 1 to 4 of figure 6a which may be used to select a single tone from a set of 16 tones, spaced 1 MHz apart near-centre frequency of 100 MHz. The major tic spacing of the ordinate is 10 dB, and the major tic spacing of the abscissa is 1 MHz. The set of four letters above each each figure correspond to passbands in figure 6(a).

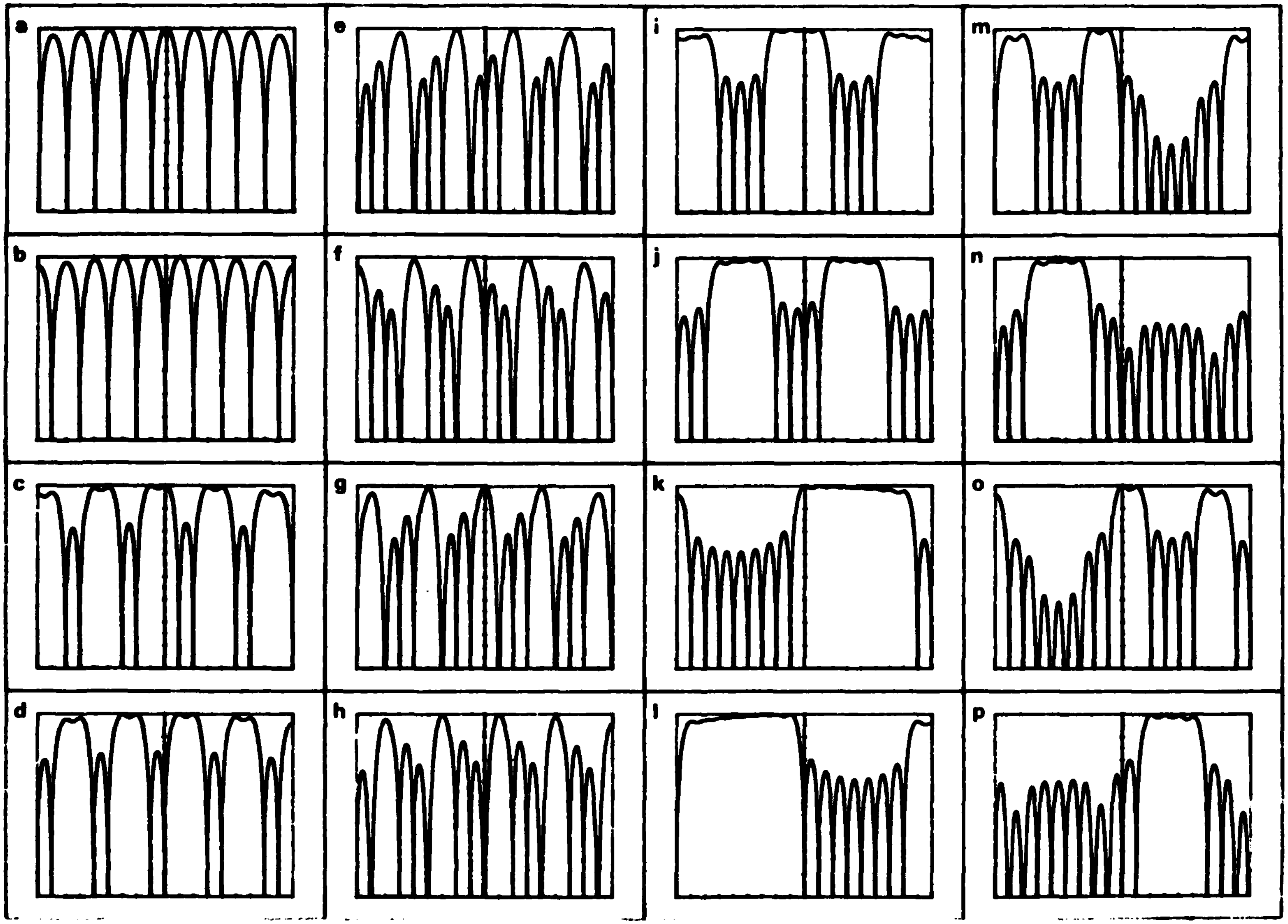
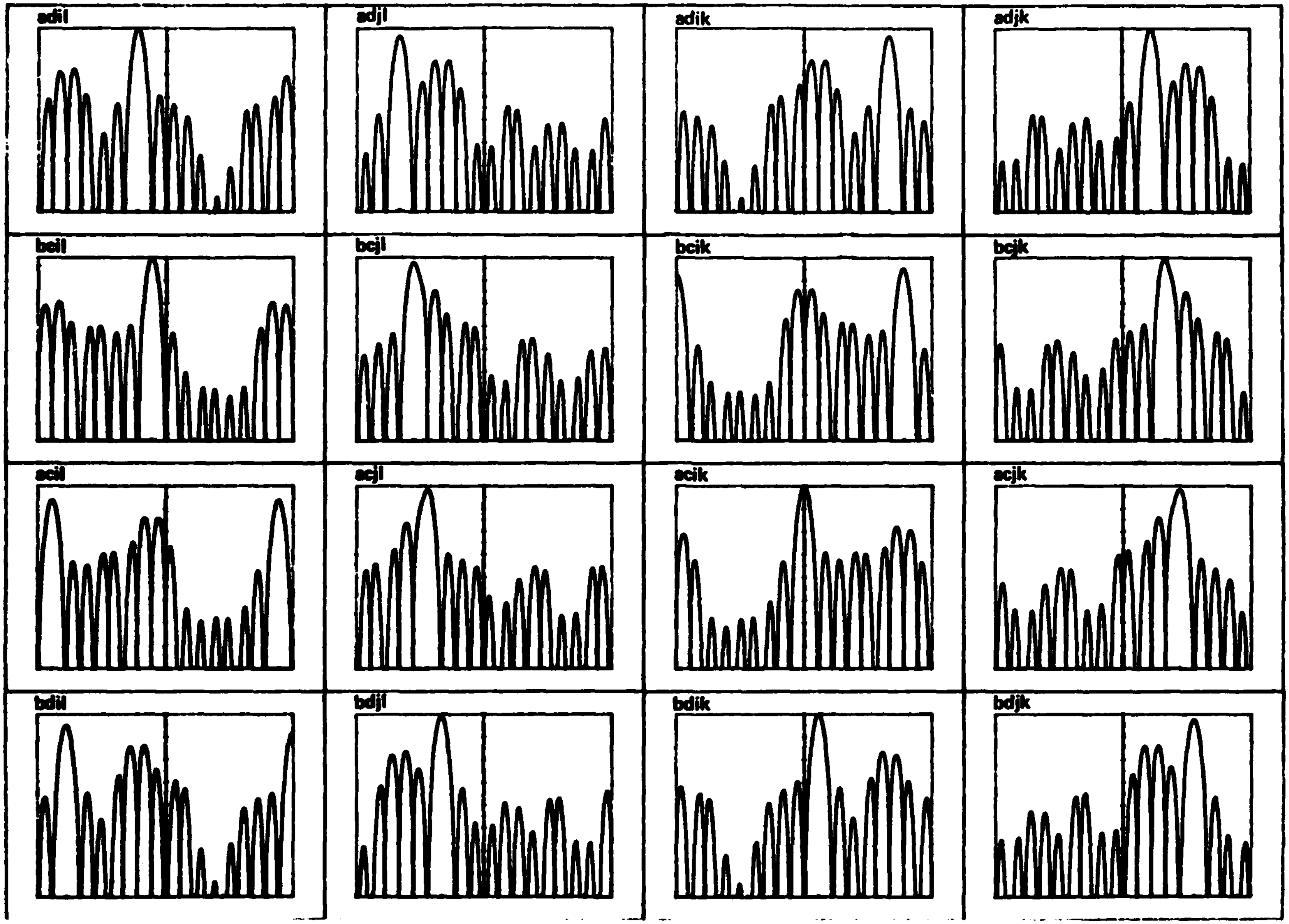


FIGURE 6a



adil
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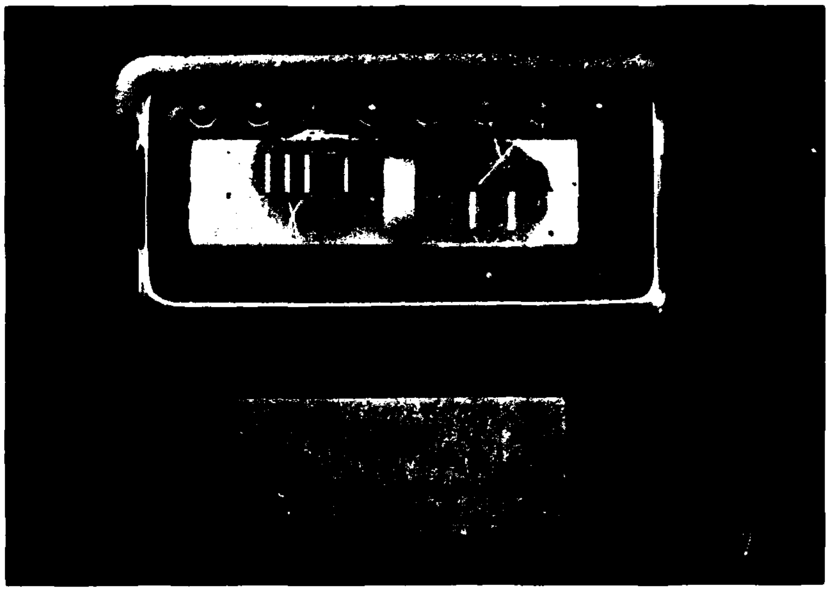
FIGURE 6b

(a)



(b)

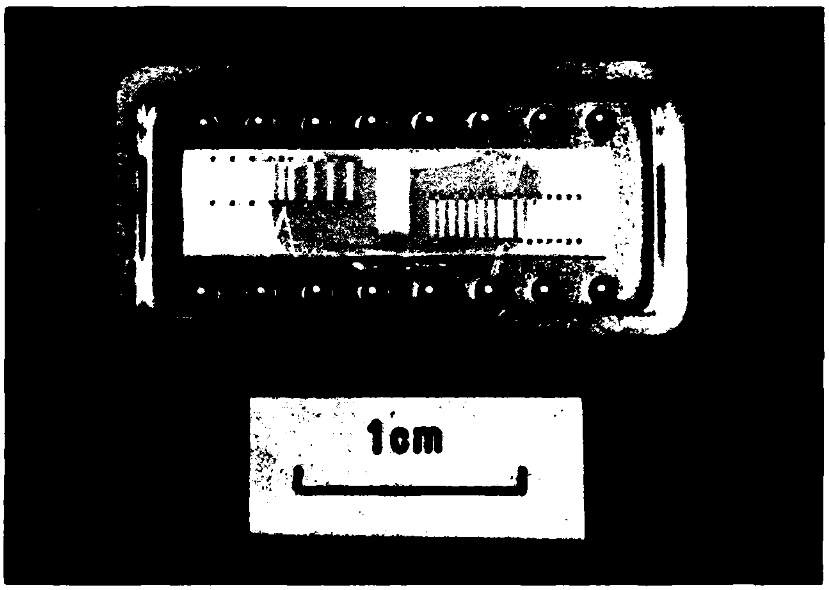


Figure 7: Photographs of two devices which employ the switchable multiple passband transducers. Both devices consist of two transducers and a full transfer multistrip coupler (5). The central element of each transducer is bonded out separately from the rest of the array to enable the response to be switched as described in the text. (a) contains transducers which correspond to N = 1 and N = 2 in figure 4. (b) contains transducers which correspond to N = 4 and N = 8 in figure 4. The component transducer in each array is a 4/5 split finger transducer.

Figure 8: Experimental results of switchable multiple passband response transducers. The order of the figure has been chosen to correspond identically with the order in figure 6a to enable direct comparison of the responses. Plots (a-d) and (i-l) involve test transducers and untuned transducers. Plots (e-h) and (m-p) are with tuned transducers and show the combined responses of the transducers in a particular device. The major tic spacing of the ordinate is 10 dB, the top of the plot corresponding to 0 dB insertion loss. The major tic spacing of the abscissa is 1 MHz. The first filter (e-h) demonstrates > 30 dB suppression of unwanted tones. The second filter (m-p) demonstrates > 25 dB suppression of unwanted tones. A tuned insertion loss of 25 dB is expected for the devices used in series.

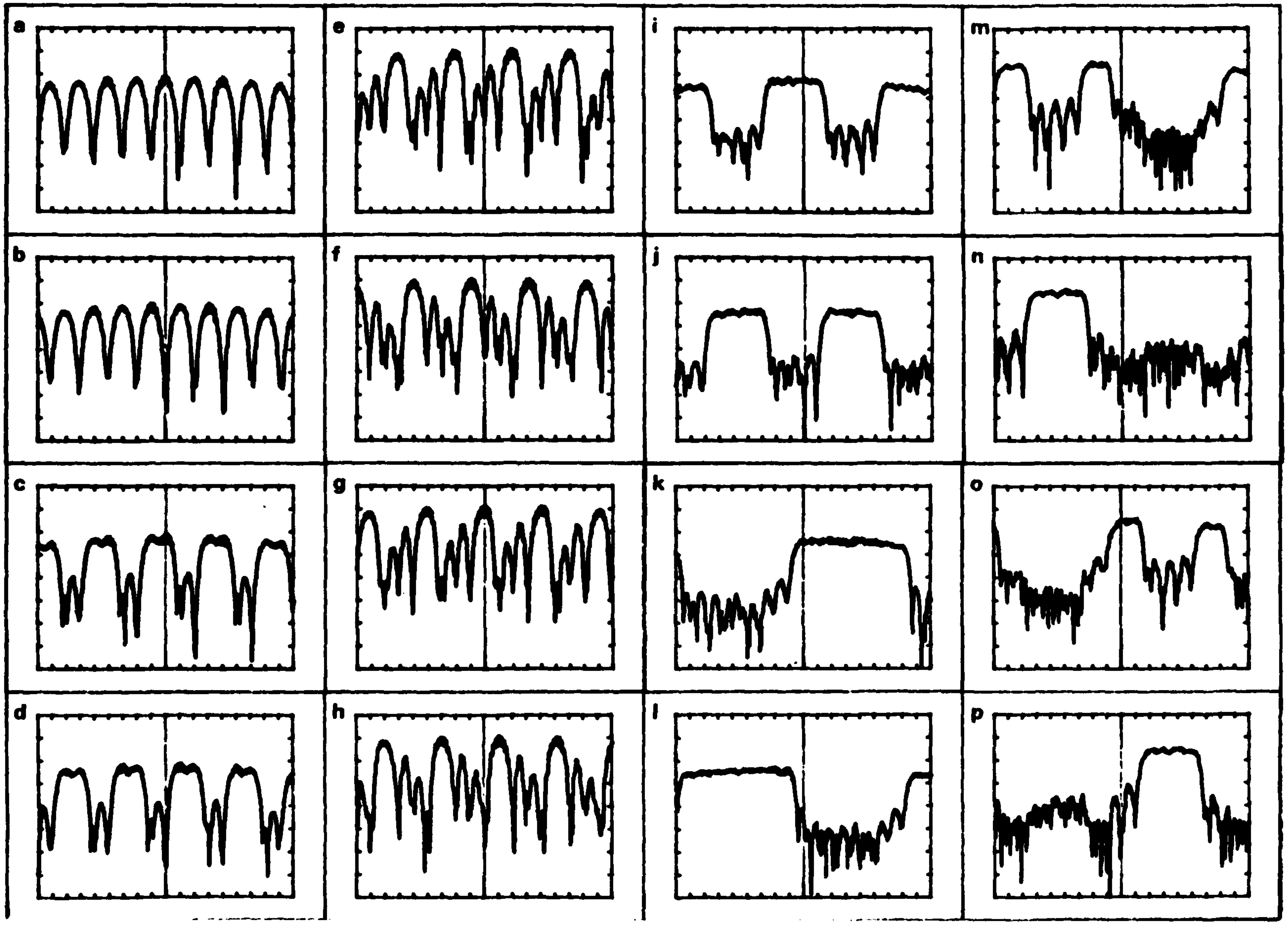


FIGURE 8

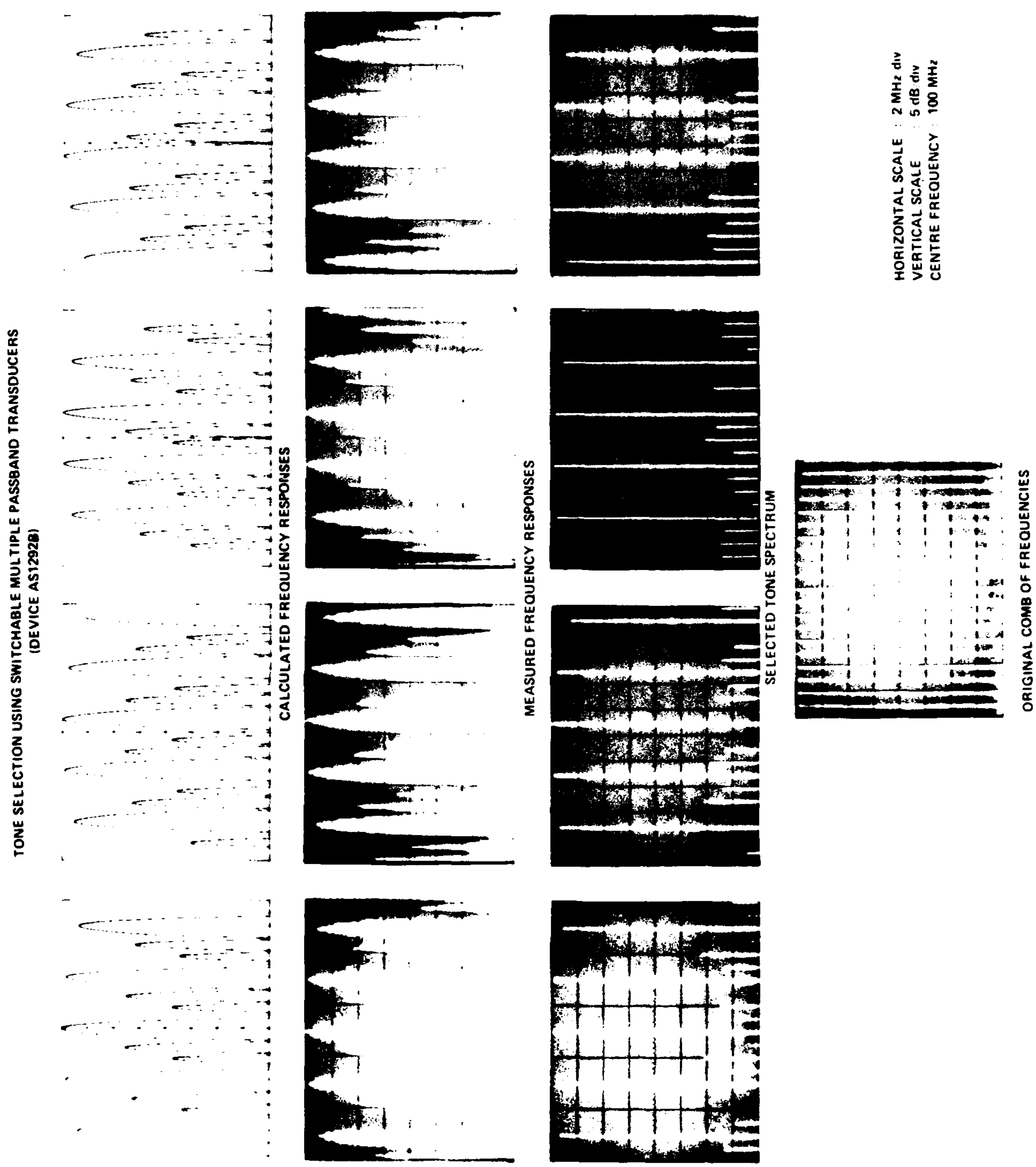


Figure 9: This figure demonstrates the use of two switchable multiple passband tranducers to select every fourth tone of a continuous comb of frequencies where the inter-tone separation is 1 MHz. The measured frequency responses can be compared directly with the calculated responses. The final tone selection results in > 30 dB suppression of unwanted tones and an insertion loss ≈ 10 dB for the wanted tones. (The device used is identical to fig 7(a)).

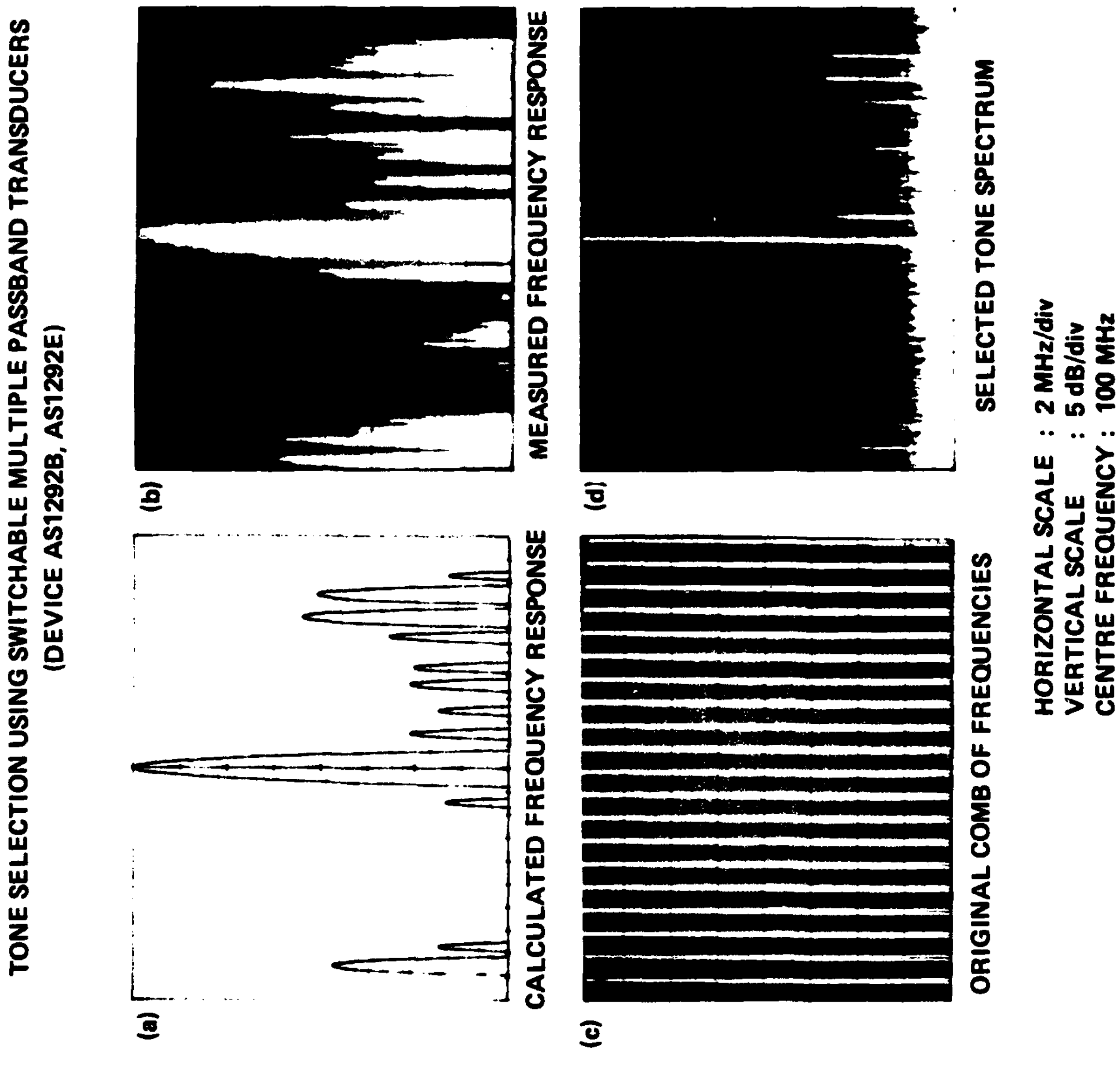
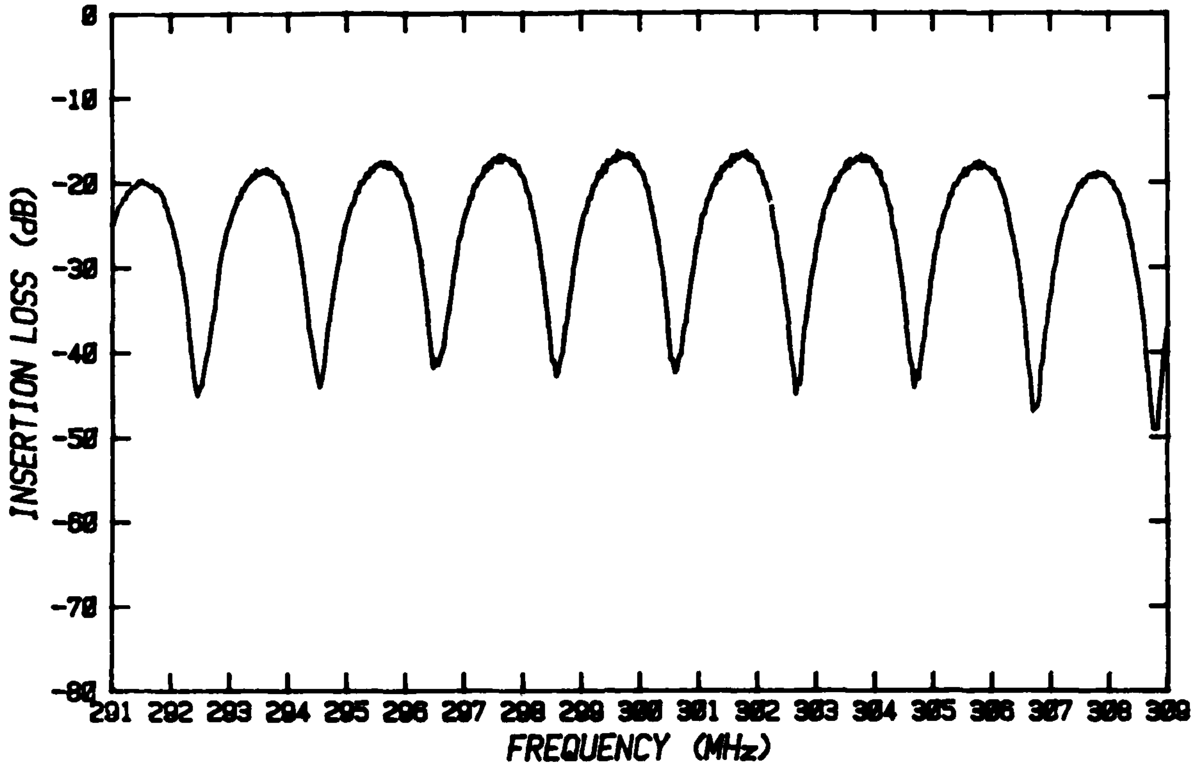


Figure 10: The use of four switchable multiple pass-band transducers to select a single tone from a continuous comb of frequencies where the inter-tone separation is 1 MHz. The final tone selection results in > 25 dB suppression of mounted tones and an insertion loss of ≈ 25 dB for the wanted tone. There are additional tones present in this configuration, spaced 16 MHz to either side of the required tone. These can be eliminated by additional envelope restricting filters.



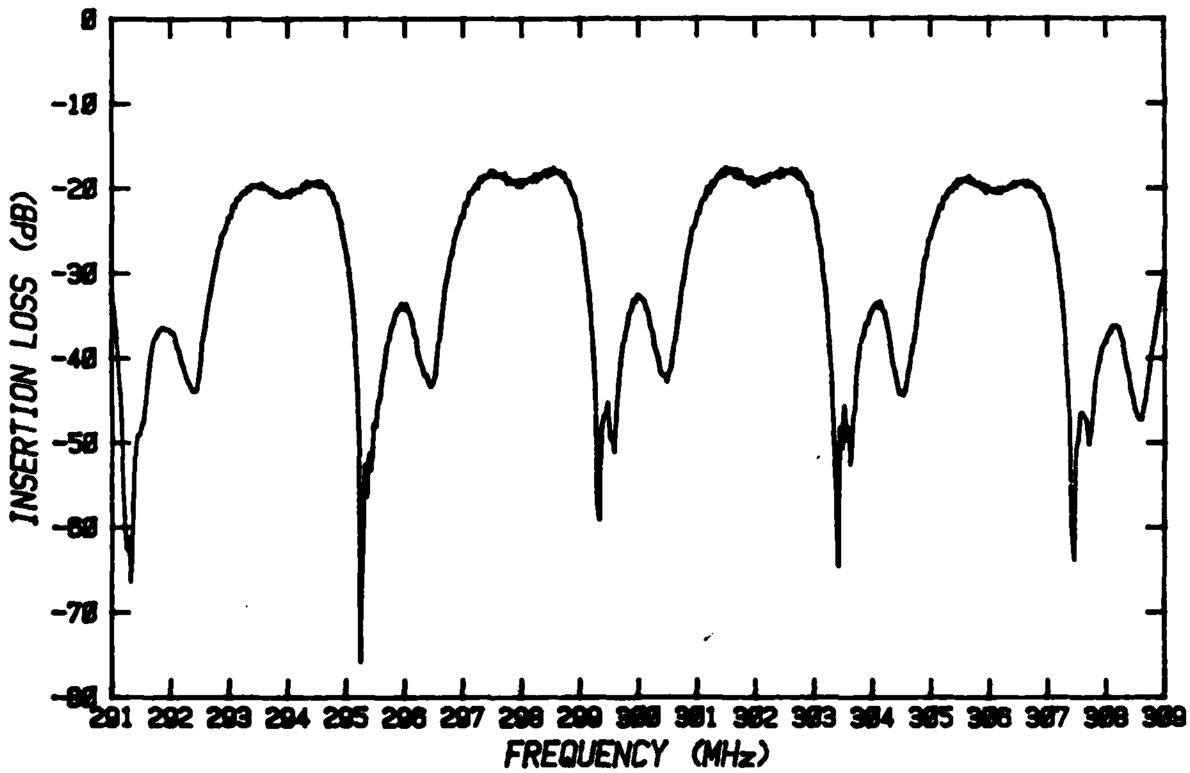


Figure 11: The third harmonic responses of the individual transducers of device a (figure 7). As the multistrip coupler does not operate at 300 MHz the responses are between the untuned multiple passband transducers and an external test transducers. Both of these responses have been shown to exhibit the same switching nature as the fundamental response.

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